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REPORT R-1656

UNITED STATES ARMY MUNITIONS COMMAND

FRANKFORD ARSENAL

PROPELLANT ACTUATED DEVICE
FOR
PERCUTANEOUS INOCULATION

by

CHARLES J. LITZ, Jr.

OMS Code 5110.22.011
DA Project 5S02-06-001

October 1962

PHILADELPHIA 37, PA.

REPORT R-1656

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PROPELLANT ACTUATED DEVICE FOR PERCUTANEOUS INOCULATION

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October 1952

ABSTRACT

A study was made to determine the feasibility of using the energy of propellant to perform a percutaneous inoculation (administer medication through the skin without an incision). A PAD percutaneous unit was designed, fabricated, and tested in the laboratory. This unit was 3-3/8 in. long by 7/8 in. diameter. It was powered by a modified T14E2 electric ignition element, and used a 0.0031 inch diameter sapphire nozzle. Twenty firings were made in the laboratory, demonstrating the feasibility of this PAD percutaneous inoculator.

It is recommended that continued studies and testing be performed to perfect and make available an automatic PAD percutaneous inoculation unit for field use.

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FOREWORD

The research work described in this report was performed by the Frankford Arsenal, U.S. Army Munitions Command, Philadelphia, Penna., and was sponsored by the U.S.Army Research Office-Durham, Durham, N. C. The work was accomplished under Army research project order AROD N-6-62, dated 15 January 1962. Dr. Sherwood Githens, Jr., Deputy Chief Scientist of the Army Research Office was the project officer.

The research program was conducted from January 1962 to July 1962, and was carried out by the Pitman-Dunn Laboratories, Research and Development Group, Frankford Arsenal, under the direction of Mr. Charles J. Litz, Jr, project engineer and chief investigator.

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INTRODUCTION

The administration of medication through the skin (both the epidermis and dermis) into the subcutaneous tissue, without an incision, is known as percutaneous inoculation and has been used by medical personnel for some time. In such inoculations, the medication is forced through a small nozzle (placed next to the skin or epidermis) which directs the liquid medication into a fine jet, enabling skin penetration. Recently, the Medical Equipment Development Laboratory (MEDL), Fort Totten, New York, has developed and satisfactorily demonstrated, and now uses a hand-held, hydraulically loaded, electrically powered, manually operated injection gun to inoculate groups of people.(1)* A medication-injection device such as this, but which would function automatically and effectively administer medication percutaneously, would have definite advantages in both field service and space travel.

Frankford Arsenal personnel conceived the idea of employing conventional solid propellant as a primary source of energy for such a device. Based on this concept, a patent disclosure was issued and a technical proposal was drafted and forwarded to the U.S. Army Research Office-Durham (AROD) for consideration. Subsequently, AROD authorized Frankford Arsenal to study such a device by establishing Research Project N-6-62, "PAD for Percutaneous Inoculation."

At the request of AROD, Frankford Arsenal personnel from the Propellant Actuated Devices Division visited the Walter Reed Army Institute of Research, Washington, D. C., and discussed the project with medical personnel. At that time it was pointed out by the medical personnel that a PAD percutaneous injection unit which could be worn strapped to the body of the soldier in the field and which would sense the presence of nerve gas and automatically inject atropine into the soldier under the nerve gas attack, would have definite advantages and could gain wide use, if perfected.

INITIAL STUDY

At the onset of the project and in the interest of economy (funds and time), it was decided to use the sapphire nozzle of the MEDL injection gun. Such a nozzle was obtained and became a part of the PAD percutaneous unit (Figure 1). In addition to the nozzle,

*See REFERENCES.

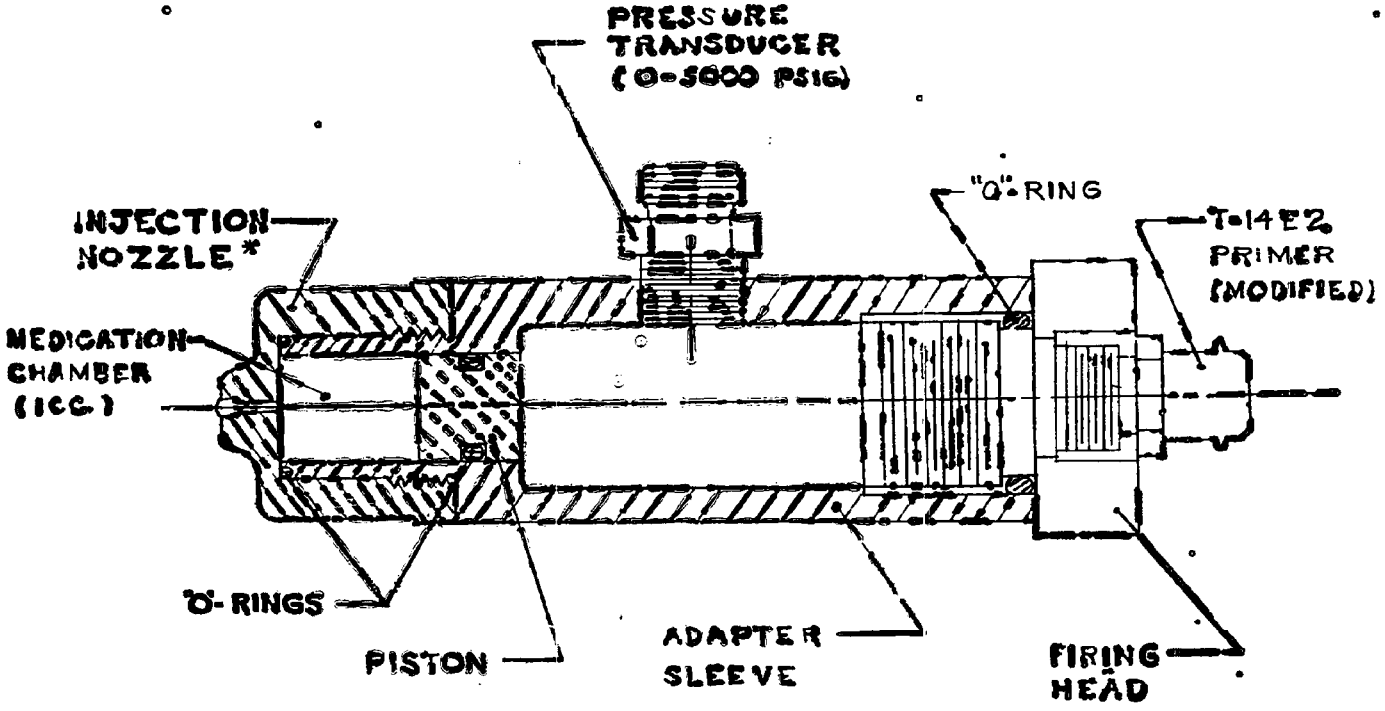


Figure 1. Assembly drawing, PAD Percutaneous Medication Injector

specific operational parameters of the hypodermic jet injection apparatus were also obtained from MEDL. The significant data obtained are listed in Appendix A.

Using the spring force and the area of the plunger piston, the pressure developed within the MEDL unit was computed. The initial pressure is 6100 psi; the final pressure, after 0.557 inch stroke, is 455 psi. It was assumed that if the PAD unit developed the pressure profile of the MEDL unit, the required free stream velocity necessary for percutaneous inoculation would be attained.

Based on the above, pressure and volume relationships were calculated for propellant for the PAD percutaneous unit, using the perfect gas law and an isentropic analysis. Details of this analysis are presented in Appendix B.

DESIGN OF COMPONENTS

After the propellant analysis (Appendix B) was completed, a laboratory test model of the PAD percutaneous unit was designed with an initial propellant chamber of 0.35 $in.^3$. As fabricated, the PAD unit (Figures 2, 3, and 4) contained a moveable piston and a 1 cc (0.061 $in.^3$) liquid medication chamber.

The unit was designed so the initial volume could be varied by inserting ring-type slugs. To assure protection of the nozzle from a high peak pressure, it was decided to test fire the unit first with the largest initial volume. For a given propellant charge, the larger volume would result in a smaller pressure.

From the stress analysis performed (Appendix C), it was seen that the PAD test unit was over-designed. Thus, the need for designing a smaller, more compact, PAD percutaneous unit for future use was apparent.

TESTING

For the purpose of laboratory testing, a standard ignition element, the T14E2, was modified and used. Figure 5 is a cross-section view of the modified T14E2. By means of this modification, energy of the standard T14E2 ignition element (which has a 1-1/2 grain lead styphnate pellet) was supplemented with three grains of 320 ball propellant loaded in a caliber .22 rim fire cartridge case.

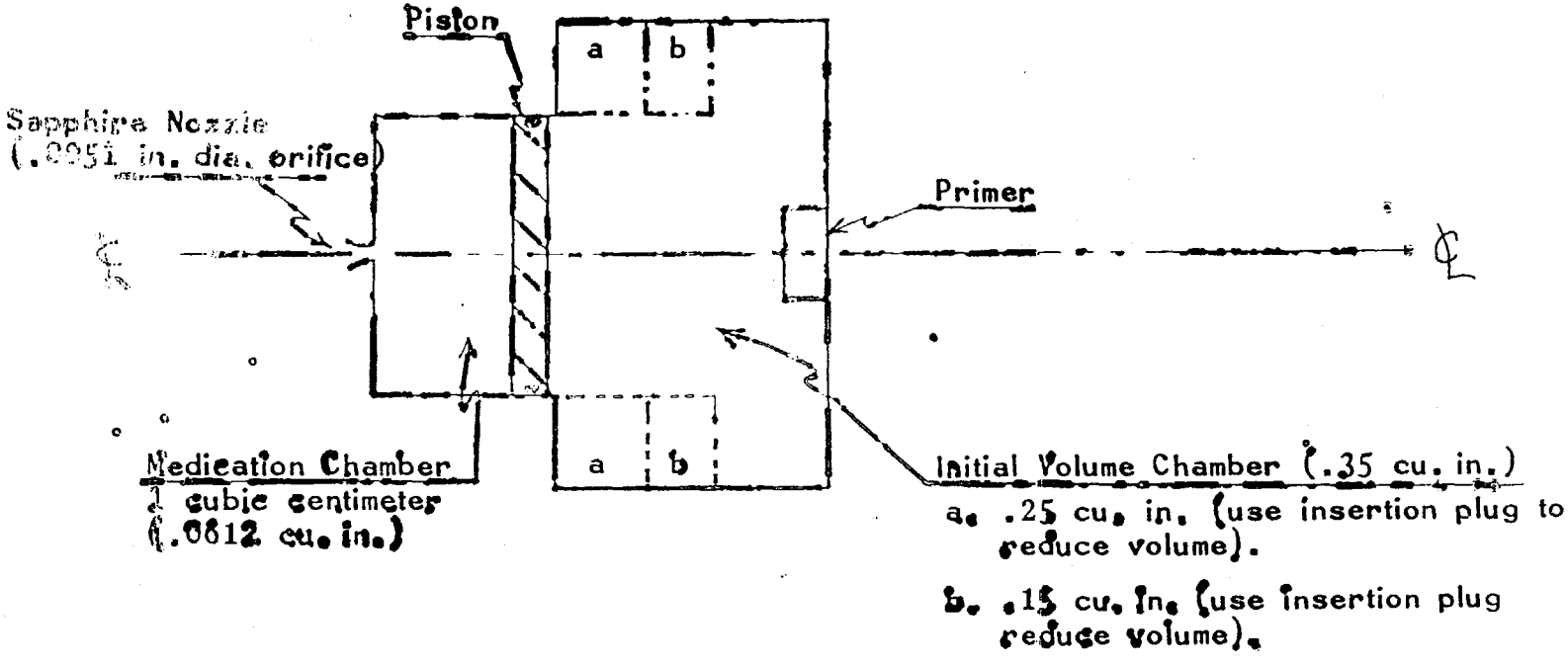


Figure 2. Concept drawing, Laboratory Test Unit with Variable Internal Volume

36.231.S2787/ORD.62

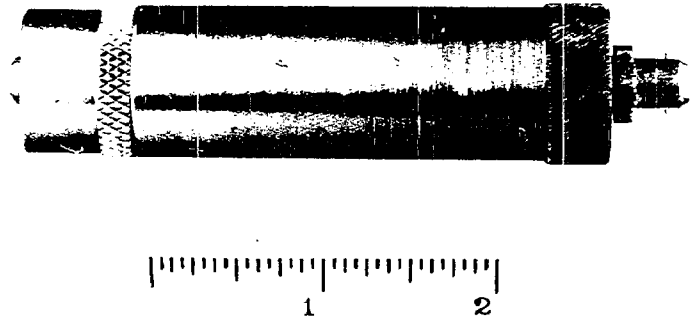
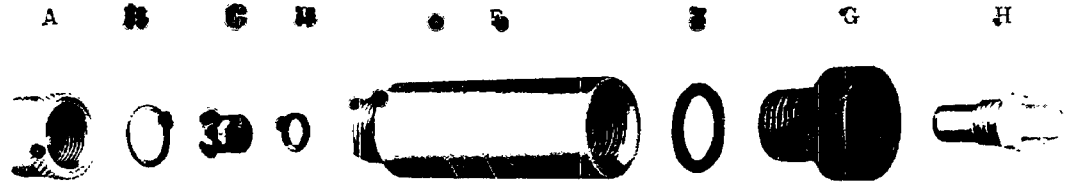


Figure 3. PAD Percutaneous Medication Injector (Test Model)

36.231.S2788/ORD.62



A. Nozzle
B. "O" Ring
C. Piston
D. "O" Ring
E. Body
F. "O" Ring
G. Firing Head
H. Modified T1E2 Element

Figure 4. PAD Percutaneous Medication Injector (Exploded View)

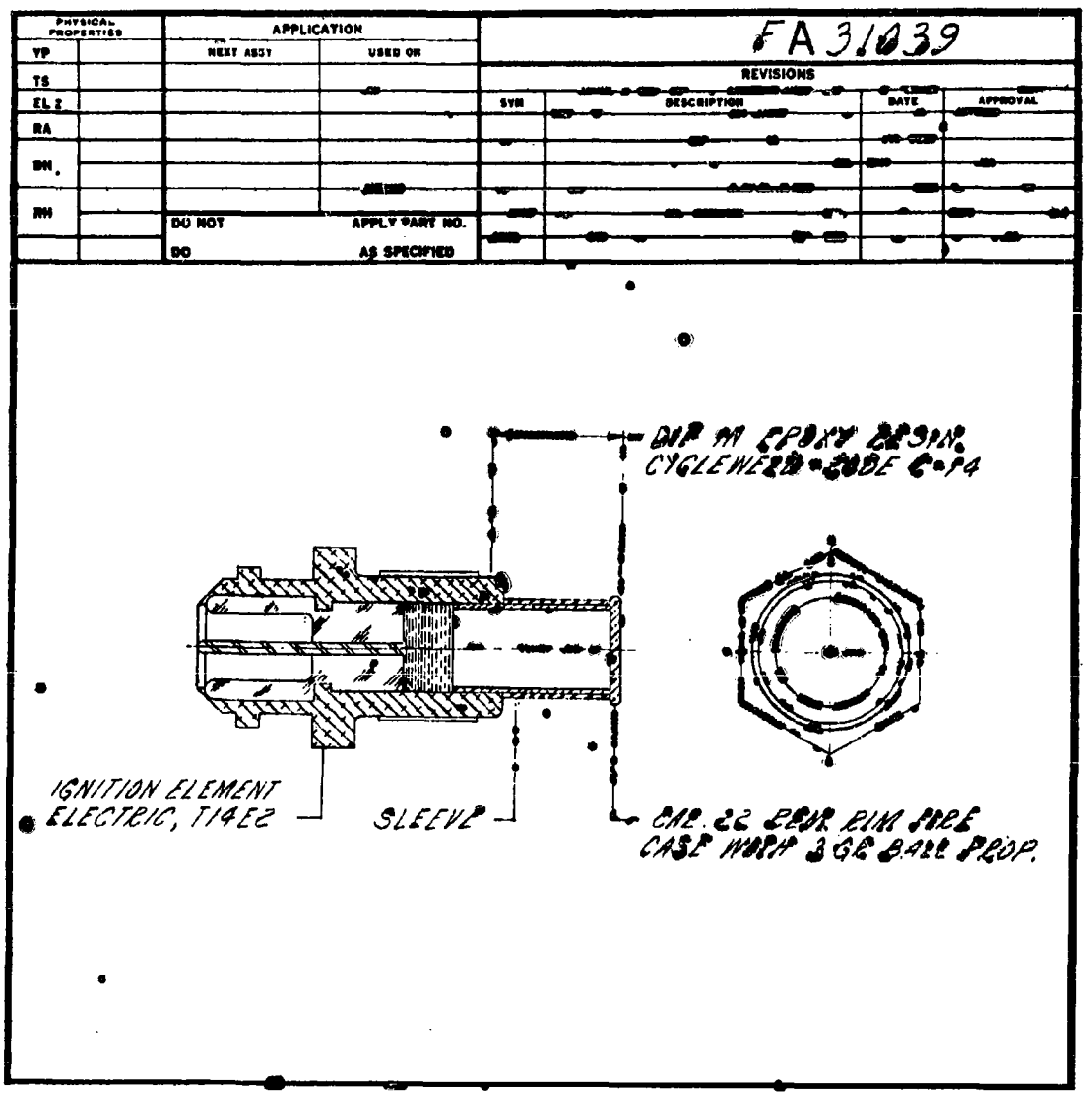


Figure 5. Assembly drawing, Modified T14E2 Electric Ignition Element

To accommodate this, a small aluminum sleeve, 1/8 inch shorter than the case, was slipped over the case mouth. This assembly was then dipped into epoxy resin for sealing. The chemical composition of the propellant used is presented in Appendix D.

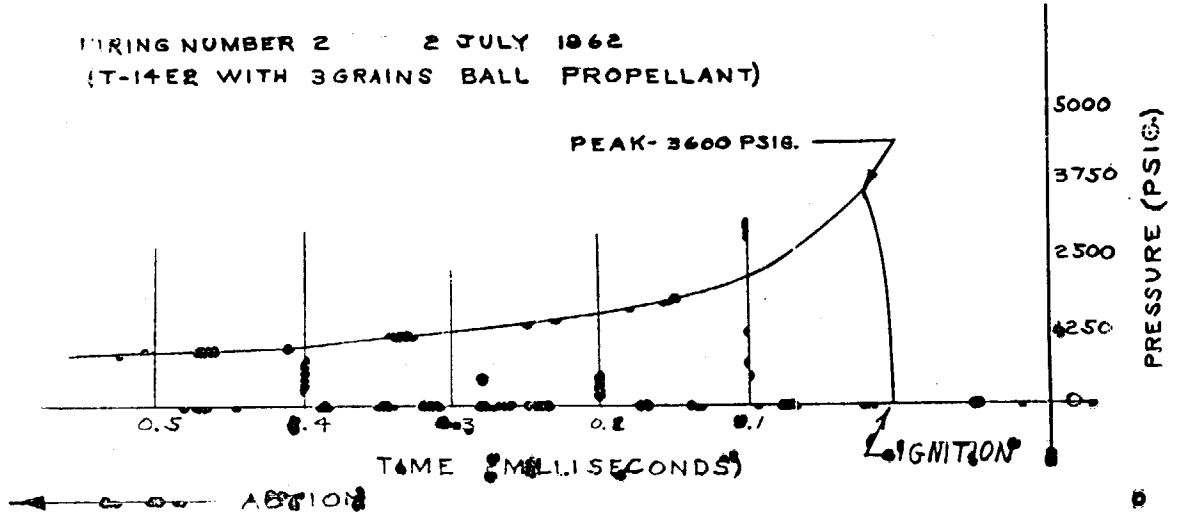
Tests were conducted using a hand-operated impulse generator (output of at least two amperes) to fire the ignition elements. Pressure-time curves were obtained using a Visicorder and a Dynisco (0 to 5000 psig) miniature pressure transducer.

Twenty firings were conducted. After the fifth firing, since the peak pressure recorded was less than the 4100 psi, the internal initial volume was decreased from 0.35 in.^{3} to 0.30 in.^{3} by inserting a hollow ring into the propellant chamber. Calculations for the reduction of the pressure chamber are presented in Appendix E. Figures 6 and 7 are typical performance curves. Table I lists the test data obtained.

In general, the results of the tests were satisfactory. All the simulated inoculant was forced through the nozzle. (Colored water was used to simulate the inoculant fluid.) The PAD unit was disassembled after each test and inspected. There was no evidence of damage to either the sapphire nozzle or the tube body, and there was no visible trace of propellant residue in the medication chamber.

With one exception (where the nozzle was clogged), there was no propellant blow-by, indicating that the O-ring on the piston had satisfactorily isolated the propellent gases from the medication. The nozzle clogging was due to a defective O-ring which permitted some foreign material to plug the nozzle. The material was removed, a new O-ring inserted, and the unit continued to function satisfactorily.

High speed movies (2880 frames/second, in color) were made of rounds 15 through 20. On rounds 15 through 19, the PAD unit was fired into flesh-simulating material placed next to the nozzle. This material was a gelatin substance (approximately 1/4 to 1/2 inch thick) normally used for small arms studies. The colored inoculant penetrated the gelatin material with a fine, needle-like stream. A container of water placed behind the gelatin material was used to receive the excess ejected fluid. Figure 8 is a color photograph of the test and shows penetration of the gelatin material by the PAD percutaneous medication injector.



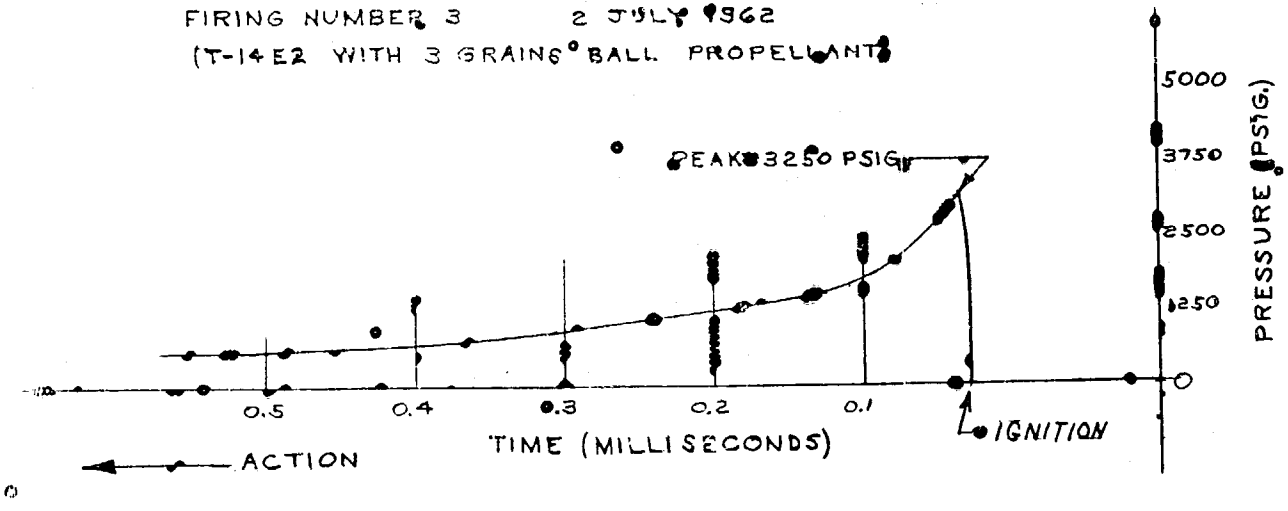


Figure 6. Typical Performance Curves, Rounds Nos. 2 and 3

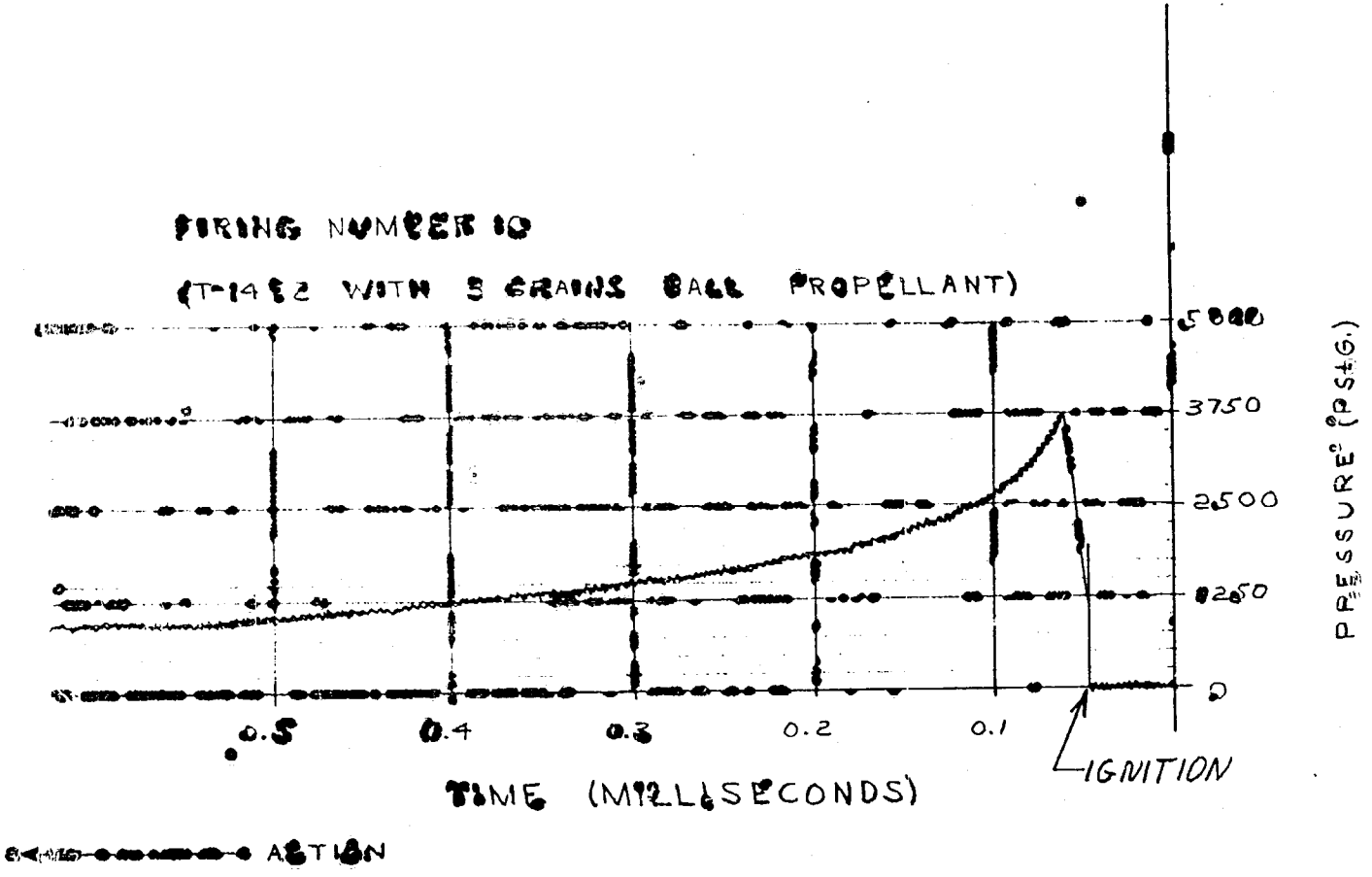


Figure 7. Actual Performance Curve, Round No. 10

TABLE I. Summary of Firing Data

Round No.	Peak Pressure (psig)	Notes
1	Not recorded	1
2	3600	2,3
3	3250	
4	2900	
5	3400	4
6	3200	
7	3750	5
8	3250	6
9	3750	
10	3800	
11	3270	
12	3358	
13	3200	
14	2800	
15	Not recorded	7
16	Not recorded	
17	Not recorded	
18	Not recorded	
19	Not recorded	8
20	Not recorded	9

Notes:

1 - First total firing with a reduced charge, consisting of an M52A3 primer, which is standard for the 20 mm round. The piston did not complete stroke due to insufficient pressure.

2 - Modified T14E2 ignition element used for all subsequent firings.

3 - An 0.047-inch cardboard, backed up with several thicknesses of paper, was placed next to the nozzle to measure the penetration of the simulated medication for rounds 2 through 7.

4 - Initial volume of propellant chamber decreased from 0.35 to 0.30 $in.^3$.

5 - Defective primer.

6 - Gelatin flesh simulator used for rounds 6 through 19.

7 - Pressure not recorded; instead, high speed (2880 frames/second) motion picture coverage was used for all subsequent tests.

8 - Sapphire nozzle clogged; piston did not complete stroke.

9 - Simulated medication fluid ejected into free air.

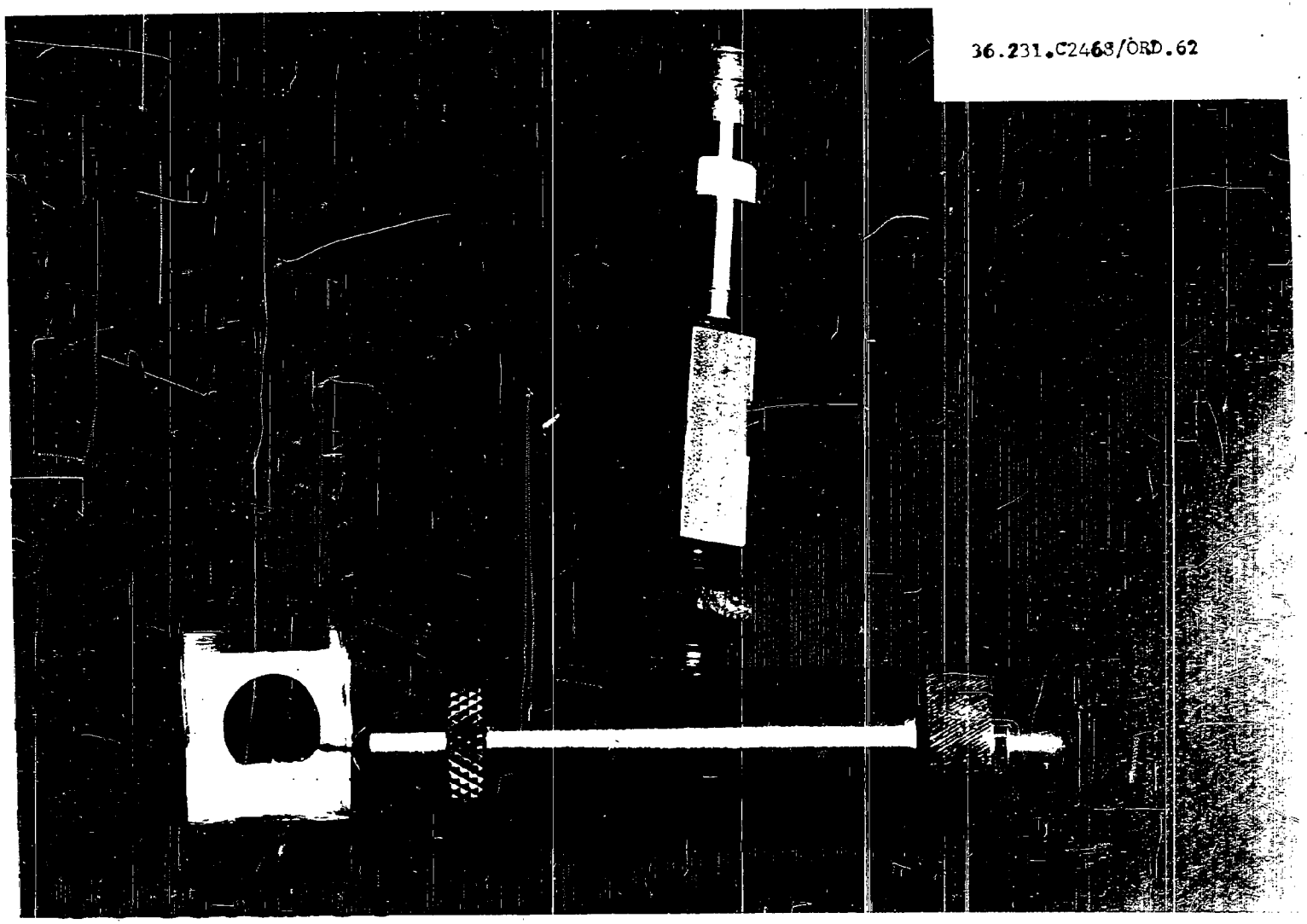


Figure 8. Penetration of Simulated Flesh (gelatin) Percutaneous Medication Injector

CONCLUSIONS

The feasibility of the PAD percutaneous medication inoculation unit has been demonstrated. Thus, the basic concept as presented in the Frankford Arsenal proposal (AROD N-61) has been removed from the realm of abstractness.

RECOMMENDATIONS

It is recommended that studies with the PAD percutaneous unit be continued. Particular emphasis should be placed on improving the performance and safety factors of the laboratory test model to make it suitable for tests on live subjects. Testing with live animals would naturally precede personnel evaluation studies.

FUTURE WORK

A unit such as the PAD percutaneous medication injection unit, with its automatic feature, could be used in space travel or under CBR (chemical, biological, and radiological) conditions. For example:

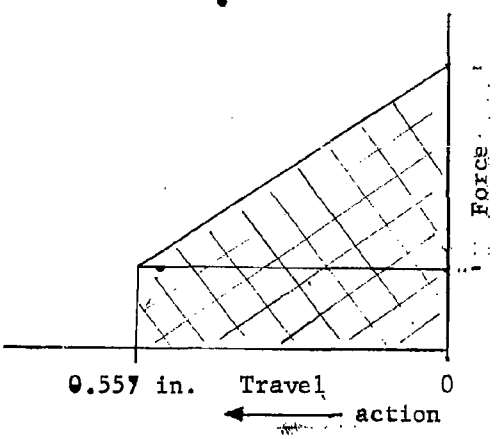
1. In space travel, the need for an automatic, remotely actuated, medication-administering device is evident. Such a device would replace the presently self-administered unit used in space (see Appendix F). Medications administered to personnel in space are designed to help offset injuries and/or uncomfortable sensations in flight, and to counteract physical and psychological disabilities resulting from gravitational differences or atmospheric variations.

2. Nerve gas is odorless, and the Army has developed a nerve gas detector (Appendix G) which senses the presence of such gas, sounds an alarm, and causes lights to flash. A spring-loaded hypodermic needle attached to a vial containing the liquid medication (atropine) to offset the effects of nerve gas, is currently available for use in the field. The PAD percutaneous medication-injection unit, if incorporated with such a detector (as discussed in Appendix G) could be used to administer atropine automatically under nerve gas attack. This automatic injection can be accomplished by means of a radio transmitter, energized by the gas sensor, and a miniature radio receiver, attached to the PAD unit. On receiving the transmitted signal, the radio receiver fires the propellant charge, causing the PAD percutaneous unit to inject the atropine.

APPENDIX A

FORCE-STROKE DATA FOR "MEDL" UNIT

A spring is used as the source of energy to force a 3/8 inch diameter piston plunger rod forward and, subsequently, to force the medication through the 0.0051 inch diameter sapphire nozzle. The spring has the following characteristics.



Initial Force: 450 lb
(Pressure Developed: 4100 psi)

Final Force: 50 lb
(Pressure Developed: 455 psi)

Also, in normal operation (using the spring) the unit ejects the 1.cc of medication into free space in approximately 0.45 second.

APPENDIX B

FEASIBILITY STUDY, PERFECT GAS LAW AND ISENTROPIC ANALYSIS

This analysis is based on an isentropic process which is a reversible adiabatic process during which no heat is transferred to or from the working substance. In the isentropic process, the working substance loses or gains energy as work, but not as transferred heat. In the actual operation of the PAD unit, some heat will be lost during the thrust cycle. It is also assumed that no piston movement will be obtained from the primer during gas evolution. The inertia in the medication fluid, caused by resistance generated on its passage through the orifice, will cause the initial volume to act in a locked-shut manner during the time of gas evolution.

From thermodynamic characteristics of all perfect gases, the equation of state for any perfect gas is

$$PV = nRT \qquad (1)$$

For real gases, Equation (1) is only approximately correct and is normally corrected for the behavior of actual gases which are not frictionless in their behavior and are composed of particles of finite volume. VanderWaals, Berthelot, or Virial coefficient equation techniques are normally used to do this.*

For this analysis, the approximate approach was used. Equation (1) may be rewritten

$$PV = g(nRTv) \qquad (2)$$

where

P = instantaneous pressure (psi)
V = internal initial volume of device ($in.^3$)
g = propellant charge weight (lb)
(nRTv) = propellant impetus, I (in.-lb/lb)
n = number of moles of propellent gas
R = universal gas constant
Tv = instantaneous gas temperature (°K) (volume constant)

*See pages 2 to 13, Reference 2.

Compute the Internal Initial Volume, V, of the PAD Percutaneous Unit.

The MEDL unit develops a peak pressure, P, of 4100 psi.

The modified T14E2 ignition element contains 1 gram lead styphnate and 3 grains ball propellant.

The impetus, I, of this propellant combination is estimated to be in the order of 2.5×10^6 in.-lb/lb.

Using Equation (2) and the above factors,

$$(4100 \text{ lb/in.}^2)(V) = \left(\frac{4 \text{ gr}}{15 \text{ gr/gm}}\right)\left(\frac{1}{454 \text{ gr/lb}}\right) 2.50 \times 10^6 \text{ in.-lb/lb}$$

$$V = \frac{\left(\frac{4}{15}\right)\left(\frac{1}{454}\right)\left(2.5 \times 10^6\right)}{4100}$$

$$V = 0.358 \text{ in.}^3$$

The initial pressure and volume for a working model can be expected to be somewhat less than that calculated. This is brought about since there will be some heat losses from the system. With the design of the PAD test unit (Figure 2), the pressure can be increased by decreasing the chamber volume.

APPENDIX C

DESIGN DATA AND STRESS ANALYSIS

The adapter sleeve is a stainless steel, cylindrical tube with 5/8-18NF-2A external and 5/8-18NF-2B internal threads on either end. A pressure pick-off hole with 1/8-27NPT threads for mounting the pressure transducer is located on one side of the unit (see Figure 3). The expected peak pressure for the test unit, which was constructed for repeated firings, was 4100 psi.

For this analysis, the distortion-energy theory of failure (von Mises-Hencky), which is the accepted criteria for the design of ductile materials under combined loads, such as a pressure vessel, was used.*

For a biaxial stress condition, the following equation applies:

$$\frac{P}{Y} = \frac{W^2 - 1}{\sqrt{(3W^4 + 1)}} \qquad (C1)$$

where

P = maximum pressure (psi)
Y = yield strength of material (psi)
W = wall ratio, $\frac{OD}{ID}$

The wall ratio for the PAD unit is

$$W = \frac{OD}{ID} = \frac{.85}{.60} = 1.416$$

The maximum pressure for the adapter sleeve is

$$\frac{P}{Y} = \frac{(1.416)^2 - 1}{\sqrt{[3\ (1.416)^4 + 1]}}$$

$$= \frac{1}{3.61}$$

$$P = \frac{160,000}{3.61}$$

$$= 44,300 \text{ psi}$$

where Y = 160,000 psi, yield stress for stainless steel.

*See page 29, Reference 3.

Margin of Safety:

$$MS = \frac{44,300}{4100} - 1 = 9.8$$

Length of Thread Engagement

The length of thread engagement is calculated from the following equation.*

$$L = \frac{3PR^2}{S_s d} \qquad (C2)$$

where

L = length of thread engagement (in.)
P = maximum internal pressure (psi)
S_s = shear strength (psi)
R = major radius of female (max) (in.)
d = minor diameter of male (min) (in.)

Equation (C2) includes a 1.5 safety factor to allow for tolerance and the distribution of stress within the engagement.

Nozzle and Firing Head - 5/8-18NF threads

For this analysis the length of thread engagement for the nozzle was considered the weakest member of the two 5/8-18NF threaded ends. The shear stress for the nozzle material is 50,000 psi, whereas the shear stress for the adapter sleeve material is 95,000 psi.

$$L = \frac{3(4100)(0.3125)^2}{(50,000)(0.5568)}$$

$$= 0.0435 \text{ in.}$$

This design is more than adequate. The actual length of thread engagement is 0.250 inch.

Pressure Tapped Hole - 1/8-27NPT threads

$$L = \frac{3(4100)(0.2025)^2}{(95,000)(0.334)}$$

$$= 0.0157 \text{ in.}$$

This design is more than adequate. The actual length of thread engagement is 0.12 inch.

*See page 23, Reference 3.

APPENDIX D

CHEMICAL COMPONENTS OF PROPELLANT

820 Ball Propellant

Nitroglycerin	9.13%	
Diphenylamine	0.97%	
Deterrent	2.50%	
Graphite	0.21%	
Total volatiles	1.35%	
Moisture	0.89%	
Ash	0.06%	
Nitrocellulose*	84.89%	
		100.00%
*Nitrogen in nitrocellulose	13.15%	

M52A3 Primer

Normal lead styphnate	40.0%	
Barium nitrate	44.2%	
Acetylene black	0.8%	
Calcium silicide	13.0%	
T.N.R. (tri-nitro-resorcinol)	1.0%	
Gum arabic	1.0%	
		100.0%

APPENDIX E

CALCULATIONS FOR REDUCTION OF PRESSURE CHAMBER

Summarized herein are calculations to determine a new initial volume. This was done to increase the peak chamber pressure of the PAD unit. The average pressure recorded for three firings (rounds 2, 3, and 4) was 3600 psi. The MEDL unit develops a peak pressure of 4100 psi (Appendix A).

For a reversible adiabatic (isentropic) process,

$$PV^K = \text{Constant during the change}$$

where

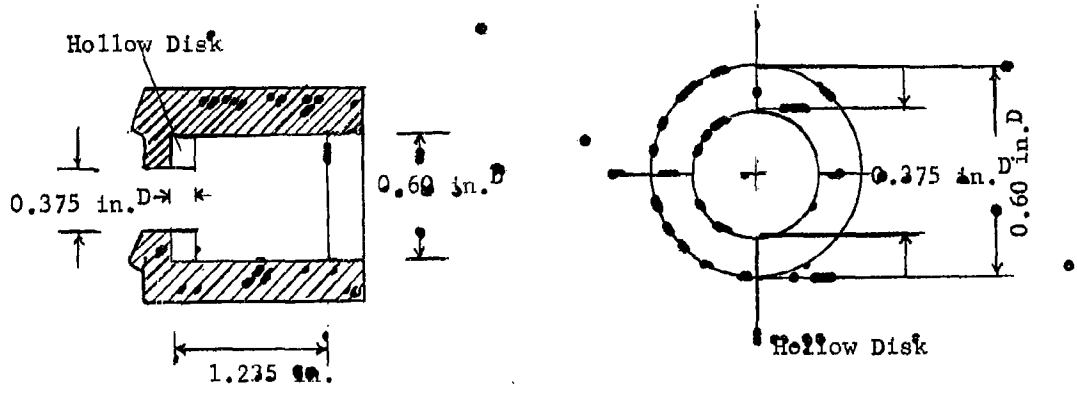
P = instantaneous pressure (psi)
V = internal volume of device ($in.^3$)
K = ratio, C_p/C_v; use 1.3

$$(3600 \text{ psi})(0.35 \text{ in.}^3)^{1.3} = (4100 \text{ psi})(V \text{ in.}^3)^{1.3}$$

$$\frac{3600}{4100} = \frac{V}{0.35}^{1.3}$$

$$V = 0.316 \text{ in.}^3$$

The internal volume of the unit was reduced from 0.35 to 0.30 $in.^3$ by inserting a 1/4 inch thick hollow disk into the propellant chamber. The size of the hollow disk used is illustrated below.



The 0.60 in. D is the inside diameter of the internal volume of the propellant chamber. The 0.375 in. D is the outside diameter of the plunger piston.

APPENDIX F

MEDICAL KIT FOR ASTRONAUTS

Drugs are a vital unit in the medical kit of the astronauts.

Medicine at Work, publication of the Pharmaceutical Manufacturers Association, said that astronauts Alan Shepard and Virgil Grissom each took along four vials of drugs with hypodermic needles attached - handy for prompt self-administration.

The publication noted that these drugs are designed to help offset uncomfortable sensations in flight, injuries, and to counteract physical and psychological disabilities resulting from gravitational differences or atmospheric variations.

The Evening Bulletin
Philadelphia
Tuesday, November 27, 1962
Date line: Washington

APPENDIX G

ARMY DEVELOPS DETECTOR TO WARN GIs OF NERVE GAS

The Army has developed an automatic device that can detect deadly nerve gases in time to save the lives of intended victims. The mechanical-chemical alarm has been ordered into production, the Army said, and should be in the hands of fighting units in a "few years." The device was described as "reasonably foolproof," based on 1,000 hours of testing in various climates.

An Army spokesman said there was no nerve gas known to medicine which could not be detected by the automatic alarm, a 28-lb device somewhat resembling a tape recorder.

* * * * *

The Army pointed out that a soldier would receive a fatal dose of nerve gas if he had to depend on his own senses to detect its presence. Nerve gases are odorless, colorless, and do not produce a physical sensation until the appearance of adverse symptoms. Then it is too late to put on masks and apply treatment.

Electric Eyes Used

The detector contains a tape on which a spot appears if a nerve agent is present. An electric eye sees the purplish spot and causes lights to flash and horns to sound. The Army said the system would not react to any agent except nerve gas.

The alarm can be carried by a soldier, or it can be mounted on an armored vehicle or a place at a distance from a command post and observed through field glasses.

It was developed by the Army chemical research and development laboratories and Air Craft Armaments, Inc., Cockeysville, Md.

The Evening Bulletin
Philadelphia
Tuesday, July 10, 1962
Date line: Washington

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3. "Ordnance Engineering Design Handbook - Propellant Actuated Devices," Ordnance Corps Pamphlet ORDP 20-270, Jul 61.

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Attn: ASRMDD-13
Capt D. R. Barron
Wright-Patterson AFB, Ohio

3 - Attn: ASNPSS-1, Mr. C. K. Hodell

1 - Attn: ASNPSP-1, Mr. A. E. Varble

1 - Attn: ASNPSP-4

1 - Attn: ASAPR, Library

1 - Attn: Aerospace Medical Laboratory,
MRG, Bldg 29

1 - Directorate of Flight & Missile
Safety Research
Attn: AFCFS-C, Col K. S. Wilson
Norton Air Force Base
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1 - Attn: ASCLF, Mr. Shannon

1 - Commander
2705th Airmunitions Wing (AMC)
U.S.Air Force
Attn: OOYIT
Hill Air Force Base, Utah

1 - Commander
Ogden Air Materiel Area
Attn: OONEAA, Mr. T. Pretti
Hill Air Force Base, Utah

U.S. NAVY

1 - Chief, Bureau of Naval Weapons
Department of the Navy
Attn: RMMO-3
Washington 25, D. C.

1 - Attn: RMMP-433

1 - Attn: RAAE-2312

1 - Commanding Officer
U.S. Naval Weapons Laboratory
Attn: Mr. R. I. Rossbacher, WC
Dahlgren, Virginia

1 - Commanding Officer
U.S. Naval Ordnance Test Station
Attn: Mr. L. R. Dallet
China Lake, Calif.

1 - Attn: Code 4574

1 - Naval Air Development Center
Attn: Cdr B. F. Burgess, USN
Ch, MA9, Aerospace Medical Div
Aero Medical Acceleration Lab
Johnsville, Pa.

1 - Commander
U.S. Naval Ordnance Laboratory
Attn: Code WC
Silver Spring, Md.

OTHER

10 - Armed Services Technical
Information Agency
Attn: TIPDR
Arlington Hall Station
Arlington 12, Va.

1 - NASA Manned Spacecraft Center
Attn: Mr. W. Simmons,
Apollo Project Office
Huston 1, Texas

1 - Solid Propellant Information
Agency
Johns Hopkins University
Silver Springs, Md.

AD- ACCESSION NO.
FRANKFORD ARSENAL, Research and Development Group, Pitman-Dunn Laboratories, Philadelphia 37, Pa.

PROPELLANT ACTUATED DEVICE FOR PERCUTANEOUS INOCULATION
by Charles J. Litz, Jr.
FA Report R-1656, Oct 62; 25 pp incl tables and illus.
OMS Code 5110.22.011; DA Project 5S02-06-001
Unclassified Report

A study was made to determine the feasibility of using the energy of propellant to perform a percutaneous inoculation (administer medication trhough the skin without an incision). A PAD percutaneous unit was designed, fabricated, and tested in the laboratory. This unit was 3-3/8 in. long by 7/8 in. diameter. It was powered by a modified T14E2 electric ignition element, and used a 0.0051-inch diameter sapphire nozzle. Twenty firings were made in the laboratory, demonstrating the feasibility of this PAD percutaneous inoculator.
It is recommended that continued studies and testing be performed to perfect and make available an automatic PAD percutaneous inoculation unit for field use.

UNCLASSIFIED

1. Propellant Actuated Device
2. Percutaneous Inoculation Unit - Propellant Actuated
3. CBR Special Application
4. Space Medicine

I. Report R-1656
II. LITZ, Charles J., Jr.
III. OMS 5110.22.011

DISTRIBUTION LIMITATIONS:
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